

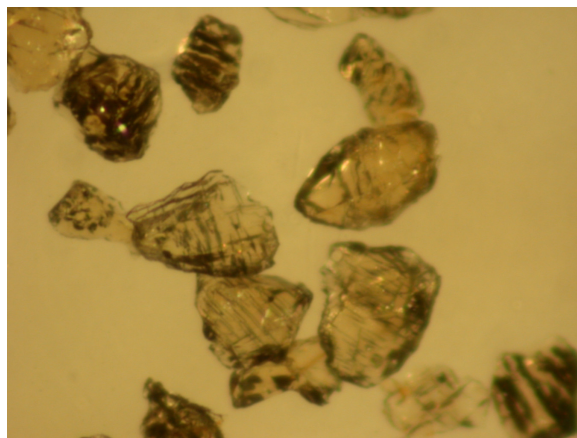
**CRYSTALLIZATION AND ALTERATION AGES OF THE ANTARCTIC NAKHLITE YAMATO 000593.**

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**Introduction:** Nakhilites are unbrecciated, olivine-bearing clinopyroxenites that probably came from Mars [e.g., 1]. A total of eight nakhilites have been identified, including five recent finds: two samples (104 g and 456 g) from the hot desert of Morocco (NWA 817 and NWA 998) [2,3] and three samples, a total weight of ~15 kg, from the Yamato Mountains of Antarctica (Y000593, Y000749 and Y000802) [4-6]. Preliminary isotopic results for Y000593 have been given by Shih *et al.* [7]. In this report, we present Rb-Sr and Sm-Nd isochron data for Y000593 and discuss the age correlation with other nakhilites and the timing of aqueous alteration on Mars.

**Samples and Analytical Procedures:** A sample of Y000593, weighing ~2.3 g, was allocated by the National Institute of Polar Research (NIPR), Japan. The sample is a coarse-grained rock and is extremely friable. One medium-sized fragment, plus fines, weighing ~0.5 g, was processed by gently crushing to grain size <149  $\mu\text{m}$ . The sample was coned and about half of the crushed sample was taken as the whole rock samples (WR1 and WR). The rest of the sample and one large-sized fragment, weighing 1.4 g, were crushed and sieved into two size fractions, 149-74  $\mu\text{m}$  and <74  $\mu\text{m}$ . Mineral separations were made from the coarser fraction using a Frantz magnetic separator. At 0.5 ampere, we obtained a non-magnetic (NM) sample, mainly plagioclase. At 0.2 ampere, we obtained a clinopyroxene (Cpx) sample from the less-magnetic fraction. A high-purity clinopyroxene (Cpx2) sample was obtained by handpicking. From the more-magnetic fraction, two olivine samples were obtained by density separation using heavy liquids (Clerici's solutions) of 3.6 and 3.95 g/cm<sup>3</sup>. The olivine (Ol) sample was handpicked from the 3.6-3.95 g/cm<sup>3</sup> fraction and consisted of yellow olivines with dark inclusions (Fig. 1). The other olivine ( $\rho > 3.95$ ) sample was handpicked from the >3.95 g/cm<sup>3</sup> fraction and displayed adhering brown alteration products, which previously have been referred to as "iddingsite". The WR, Cpx, Cpx2, NM,  $\rho > 3.95$  and Ol samples were washed with 2N HCl in an ultrasonic bath for 10 minutes to eliminate possible terrestrial contamination, if it exists, and martian alteration products. Both the residues (r) and leachates (l) of these samples, plus unleached sample WR1, were analyzed for Rb, Sr, Sm and Nd following the chemical procedures of [8]. The isotopic measurements were made on a Finnigan-MAT 261 multi-

collector mass spectrometer following the procedures of [9]. The average values of  $^{87}\text{Sr}/^{86}\text{Sr}$  for NBS 987 during the course of the study were  $0.710237 \pm 0.000014$  ( $2\sigma_p$ , 6 analyses) and  $0.710233 \pm 0.000026$  ( $2\sigma_p$ , 14 analyses), normalized to  $^{88}\text{Sr}/^{86}\text{Sr} = 8.37521$ . The  $^{87}\text{Sr}/^{86}\text{Sr}$  results reported here were renormalized to the NBS 987  $^{87}\text{Sr}/^{86}\text{Sr} = 0.710250$  of [10]. Because of the low Sm and Nd contents of the samples, Sm and Nd isotopic data were measured as  $\text{SmO}^+$  and  $\text{NdO}^+$ . The  $^{143}\text{Nd}/^{144}\text{Nd}$  results for samples reported here were renormalized to  $^{143}\text{Nd}/^{144}\text{Nd} = 0.511138$  for the Caltech Nd standard n(Nd) $\beta$  [11].

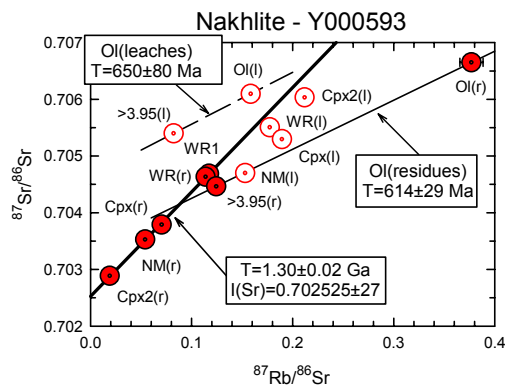


**Figure 1.** Photograph of the olivine (Ol) sample (149-74  $\mu\text{m}$  and 3.6-3.95 g/cm<sup>3</sup> fraction). The field of view is ~0.6 mm.

**Results and Discussion:** The  $^{87}\text{Rb}/^{86}\text{Sr}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  data for one unleached sample WR1 and residues and leachates from WR, Cpx, Cpx2, NM,  $\rho > 3.95$  and Ol are shown in Fig 2. If all these samples are included, they do not define a single linear array. However, samples WR1, WR(r), Cpx(r), Cpx2(r) and NM(r) form a line in the  $^{87}\text{Rb}/^{86}\text{Sr}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  correlation diagram. These five data points yield an Rb-Sr age of  $1.30 \pm 0.02$  Ga for  $\lambda(^{87}\text{Rb}) = 0.01402$  Ga<sup>-1</sup> and an initial  $^{87}\text{Sr}/^{86}\text{Sr}$  of  $0.702525 \pm 0.000027$ , using the Williamson regression program [12]. This Rb-Sr isochron age for Y000593 is in excellent agreement with radiometric ages determined previously by various methods for three other nakhilites and Chassigny [e.g., 8,13]. The initial  $^{87}\text{Sr}/^{86}\text{Sr}$  for Y000593 is within error limits of that of Lafayette [14] and Chassigny [15] but slightly different from that of Nakhla [16,17] and Governador Valadares [8]. The slight discrepancy in the

the initial  $^{87}\text{Sr}/^{86}\text{Sr}$  in nakhlites may be attributed to sampling of different flows of the same clinopyroxene-dunite lithology on Mars.

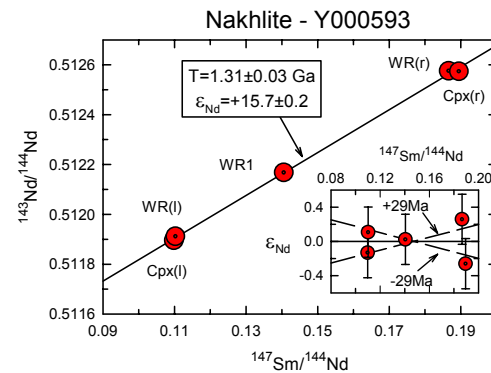
Data for the four leachates, WR(l), Cpx(l), Cpx2(l) and NM(l) lie to the right of the line. On the other hand, the olivine leachates,  $\rho>3.95$ (l) and Ol(l), lie to the left of the line. These deviations are probably due to the presence of secondary aqueous alteration products in Y000593. This secondary alteration effect has been previously reported for Gobernador Valadares and Lafayette [8,14]. The leachate samples are more radiogenic and have high Rb/Sr ratios compared with the corresponding residue samples, except for less radiogenic Ol(l). Treatment of the olivine samples,  $\rho>3.95$  and Ol, with 2N HCl dissolved 45% and 18%, respectively, by weight and effectively removed surficial alteration products. Calculated total contents of Rb from the combined data of the olivine leachate and residue samples are one order of magnitude lower than the Rb contents in the olivine separates from Nakhla [17], which indicates that our olivine samples do not contain large amounts of alkali elements, even though the olivine sample,  $\rho>3.95$ , was associated with reddish-brown "iddingsite". Tie lines between two olivine residues,  $\rho>3.95$ (r) and Ol(r), and between two olivine leachates,  $\rho>3.95$ (l) and Ol(l), provided calculated ages of  $614\pm 29$  Ma and  $650\pm 80$  Ma, respectively, which may represent an aqueous alteration event on the martian surface. These Rb-Sr ages are in good agreement with the oldest K-Ar age of  $670\pm 91$  Ma for the iddingsite sample [18] and with the Rb-Sr age of  $679\pm 66$  Ma for HCl leachates from the iddingsite-rich samples [14] from Lafayette.



**Figure 2. Rb-Sr isochron of the nakhlite Y000593.**

The preliminary Sm-Nd isochron of Y000593 is presented in Fig. 3. All five data analyzed so far, including two leachates, WR(l) and Cpx(l), define a linear array corresponding to a Sm-Nd age of  $1.31\pm 0.03$  Ga for  $\lambda(^{147}\text{Sm})=0.00654\text{Ga}^{-1}$  using the Williamson

regression program [12]. This age is in excellent agreement with the Rb-Sr age obtained from the same samples. The concordancy of Sm-Nd and Rb-Sr ages strongly suggests that Y000593 crystallized 1.30 Ga ago. The age data for this new Antarctic nakhlite provide additional evidence that nakhlites, and probably Chassigny as well, crystallized within a short period of time  $\sim 1.3$  Ga ago.



**Figure 3. Sm-Nd isochron of the nakhlite Y000593.**

An averaged cosmic-ray exposure (CRE) age of the Yamato nakhlites (Y000593, Y000749 and Y000802),  $12.1\pm 0.7$  Ma [19], is consistent within error limits with the CRE ages of Nakhla, Gobernador Valadares, Lafayette (summarized in [13]) and NWA 817 [20]. Thus, there is a strong suggestion that all the nakhlites were ejected from Mars in the same impact event.

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